

The background of the slide is a composite image of space. In the upper left, a large, reddish-orange planet (Mars) is partially visible. To its right is a smaller, grey, cratered asteroid. Dominating the center is a large, detailed view of the Earth, showing the continents of North and South America. A bright white beam of light from a rocket launch extends from the bottom center towards the Earth's horizon. At the very bottom, there are silhouettes of a lunar or planetary surface with a rover, two astronauts, and a small dome-shaped habitat with lights.

Opening Session

Update on NASA ISRU Plans, Priorities, and Activities

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LIST



Major Responses Received for ISRU Envisioned Future Priorities

Refinement of Existing EFP and Priorities

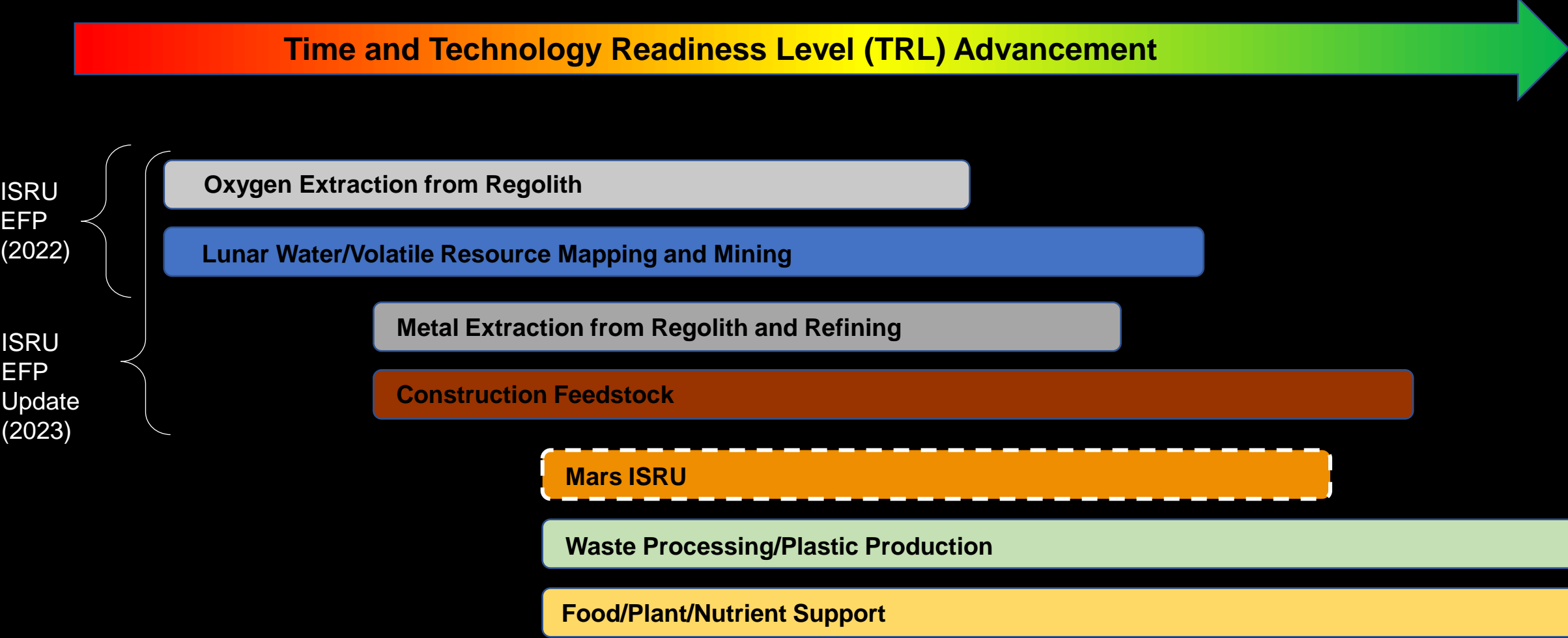
- More Technical Details Desired
- Clearer Roles and Responsibilities; Emphasize Industry/Commercial Involvement
- Refine Plan and Priorities

Programmatic Influences

- Better Promote Industry Involvement
- Increase Emphasis on ISRU in M2M Architecture
- Non-technical but overarching US Policy takeaways.
 - “Commercial ISRU requires **clear international policies and norms** associated with resource extraction and product ownership before significant investment can occur.
 - Need to deal with public perception and concerns for science impact in defining the policies and norms.”
The ‘ethics’ of ISRU and space mining need to be addressed



Multiple Areas of ISRU under Development in Phases



- Utilize STMD solicitations and internal work to progress ISRU work areas as TRL progresses
- Initial Focus was on Oxygen Extraction and Water Mining.
 - Now that they have progressed, earlier TRL solicitations moved to next phase of work (Metals and Construction Feedstock) and evaluate specific gaps or next gen high risk/high payoff concepts



Moon to Mars (M2M) Blueprint Objectives and ISRU

- NASA Moon to Mars (M2M) Blueprint Objectives officially released in Sept. 2022 at IAC
- A significant number of objectives align with ISRU in three general areas (Resource Assessment, ISRU and Usage, and Responsible ISRU)
- A significant number of Recurring Tenets are achieved with ISRU development and implementation

Green	Science, Lunar History, Science (LM), Science-Enabling (LM), Applied Science (LM)
Purple	Innovation, Lunar Infrastructure (LM), Infrastructure (LM)
Blue	Transportation and Habitation (LM)
Red	Exploration (LM)
Orange	Recurring Tenets (RT)

Resource Assessment	
AS-3 ^{LM}	Characterize accessible lunar and martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.
OP-3 ^{LM}	Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.
LPS-3 ^{LM}	Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and martian volatiles.
TH-7 ^M	Develop systems for crew to explore, operate, and live on the martian surface to address key questions with respect to science and resources.
SE-3 ^{LM}	Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.

Responsible ISRU	
SE-7 ^{LM}	Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as martian recurring slope lineae, to enable future high-priority science investigations.
OP-12 ^{LM}	Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration
RT-6	Responsible Use: conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space

Superscript text indicates the applicability to Lunar (L), Martian (M) or both (LM).

ISRU and Usage	
LI-7 ^L	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-8 ^L	Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
MI-4 ^M	Develop Mars ISRU capabilities to support an initial human Mars exploration campaign.
OP-11 ^{LM}	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
TH-3 ^L	Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.

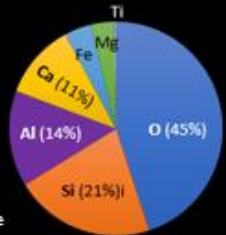
These are the Recurring Tenets; themes common across all blueprint objectives.	
RT-1	International Collaboration: partner with international community to achieve common goals and objectives
RT-2	Industry Collaboration: partner with U.S. industry to achieve common goals and objectives
RT-3	Crew Returns: return crews safely to Earth while mitigating adverse impacts to crew health
RT-4	Crew Time: maximize crew time available for science and engineering activities within planned mission durations
RT-5	Maintainability and Reuse: when practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence
RT-6	Responsible Use: conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space
RT-7	Interoperability: enable interoperability and commonality (technical, operations and process standards) among systems, elements, and crews throughout the campaign
RT-8	Leverage Low Earth Orbit: leverage infrastructure in Low Earth Orbit to support M2M activities
RT-9	Commerce and Space Development: foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation

Time and Spatial Evolution of Lunar Resources and Commodities for Commercial and Strategic Interests

- ISRU starts with the easiest resources to mine, requiring the minimum infrastructure, and providing immediate local usage
- The initial focus is on the lunar South Pole region (highland regolith and water/volatiles in shadowed regions)
 - ISRU will evolve to other locations, more specific minerals, more refined products, and delivery to other destinations

1. Polar Highland Regolith (Oxygen, Aluminum, Silicon)

Highland Regolith
(Apollo 16)

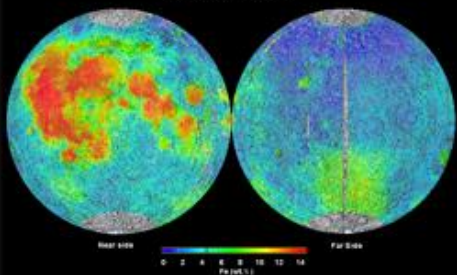


from Planetary and Space
Science, Vol. 74,

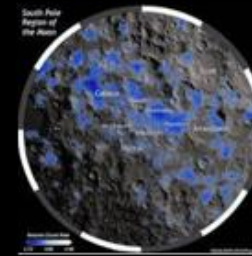
■ O ■ Si ■ Al ■ Ca ■ Fe ■ Mg ■ Ti

3. Ilmenite and Pyroclastic Glass (Iron, Titanium, Solar Wind Volatiles)

Clementine Iron Map of the Moon
Equal Area Projection



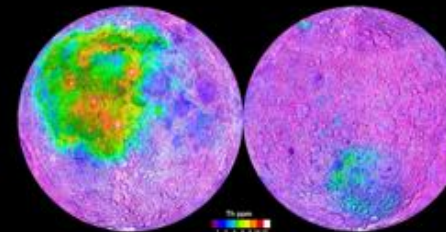
2. Polar Water/Volatiles



LCROSS Impact Volatiles	Concentration (wt%)
H ₂ O	0.6
CO	0.70
H ₂	1.40
H ₂ S	1.78
Ca	0.20
Hg	0.24
NH ₃	0.35
Mg	0.40
SO ₂	0.68
C ₂ H ₄	0.37
CO ₂	0.32
CH ₃ OH	0.16
CH ₄	0.83
OH	0.06
H ₂ O (adsorb)	0.001-0.003
Na	

Table courtesy of Tony Colaprete

4. Rare Earth Elements & Thorium



Indication of where KREEP is
(Procellerum KREEP Terrane)

Commodities

- Oxygen
- Water
- Bulk & Refined Regolith
- Raw & Refined Metals (Al, Fe, Ti)
- Silicon and Ceramics
- Construction Feedstock
- Manufacturing Feedstock
- Fuels, Plastics, Hydrocarbons
- Food/Nutrient Feedstock

Emphasize Industry Involvement



- Define Initial and Long-term Customer Needs and ISRU-derived Products
- Advance ISRU Technologies/Systems (thru solicitations, public-private partnerships, Challenges)
- Reduce Risk and Promote Investment (fundamental research, tech. dev., facilities, etc.)
- Promote Industry-led development thru End-to-end production of commodities

Exploration Phase

- Reserve Definition
- Mining and Recovering Technology Readiness

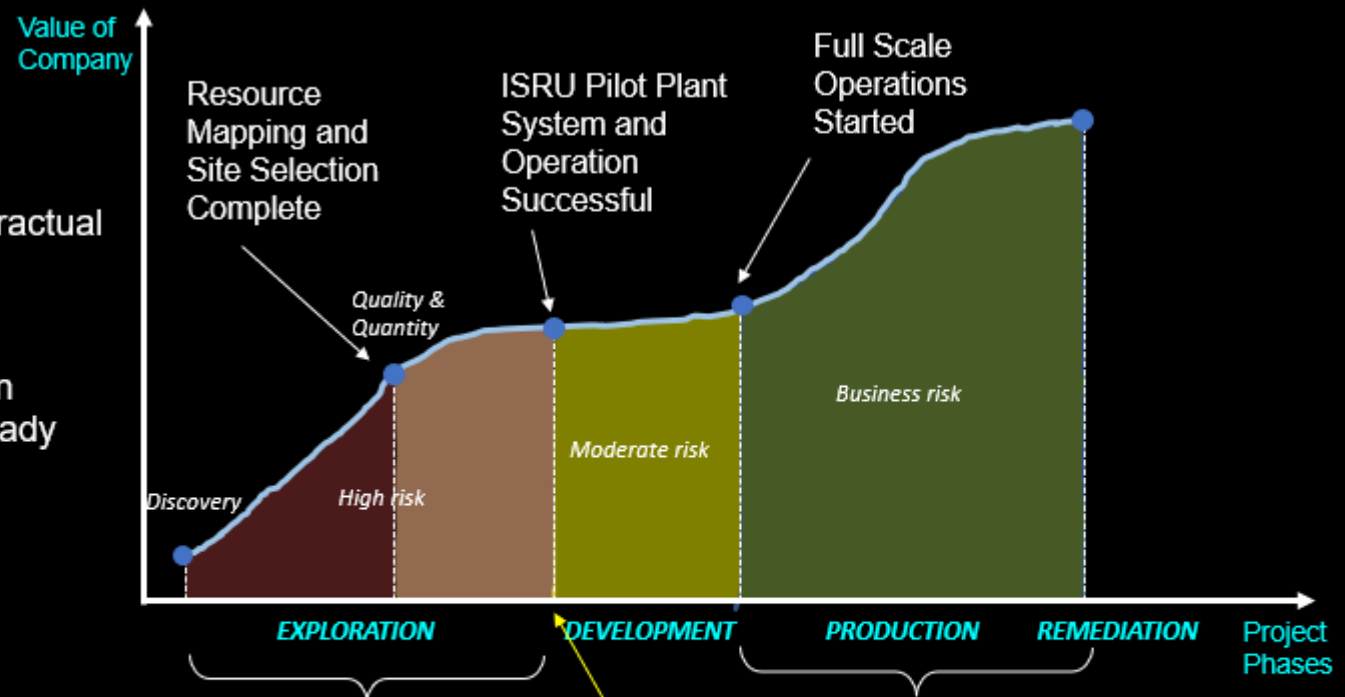
Development Phase: Feasibility study, contractual and legal aspects, and financing

Production

- Build-up Phase: Startup and initial production
- Plateau Phase: Production rate remains steady
- Decline Phase: Reserves begin to dwindle

Remediation

- Shutdown/removal of mining equipment
- Mine site reclamation



Government support in Exploration Phase may be key to lunar commercial success



Negative cash flow due to resource assessment and technology development and testing

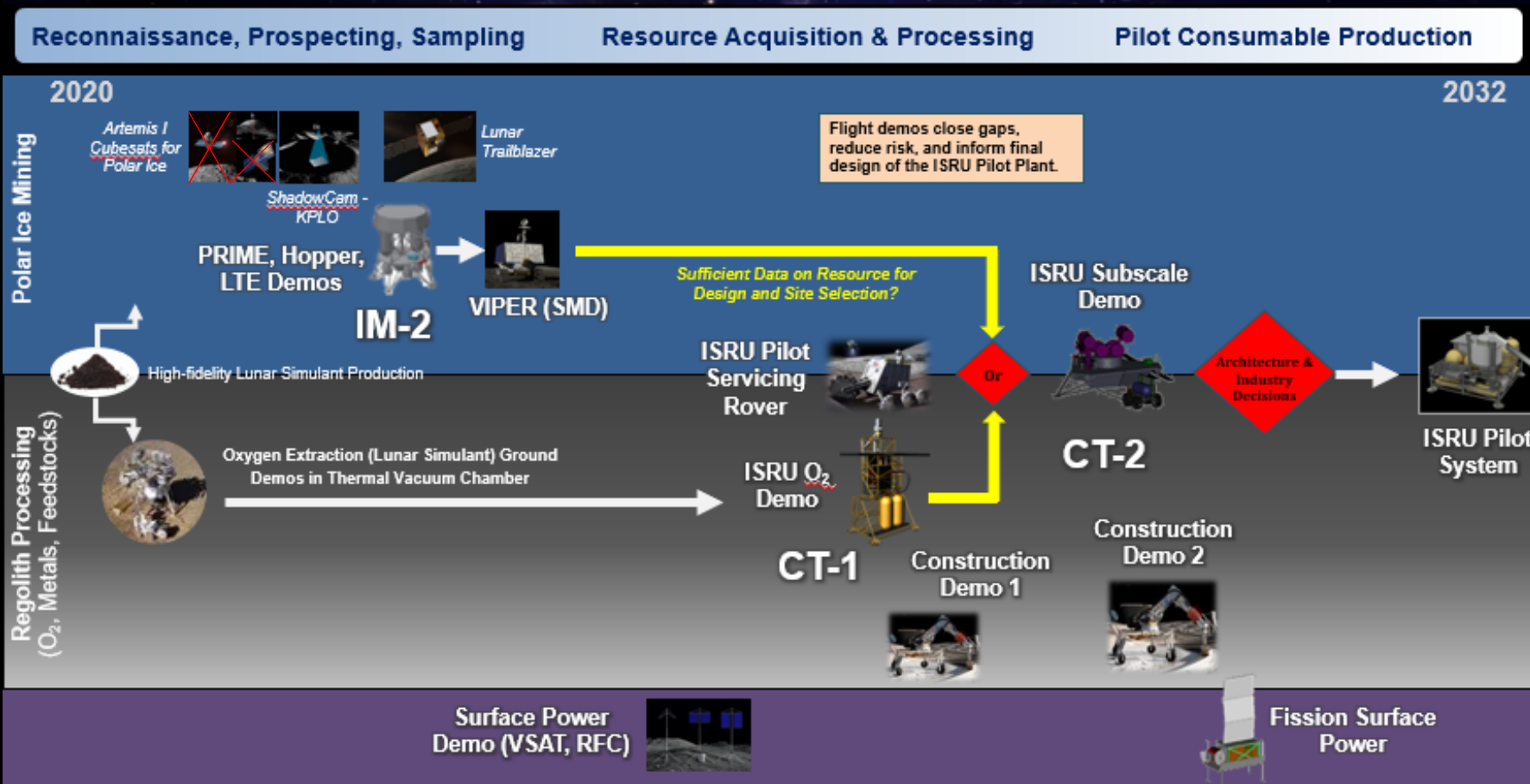
Positive cash flow due to production and selling of product

Investment risk significantly reduced after successful Pilot Plant demonstration

ISRU Path to Full Implementation & Commercialization*



**Proposed missions and timeline are contingent on NASA appropriations, technology advancement, and industry participation, partnerships, and objectives*



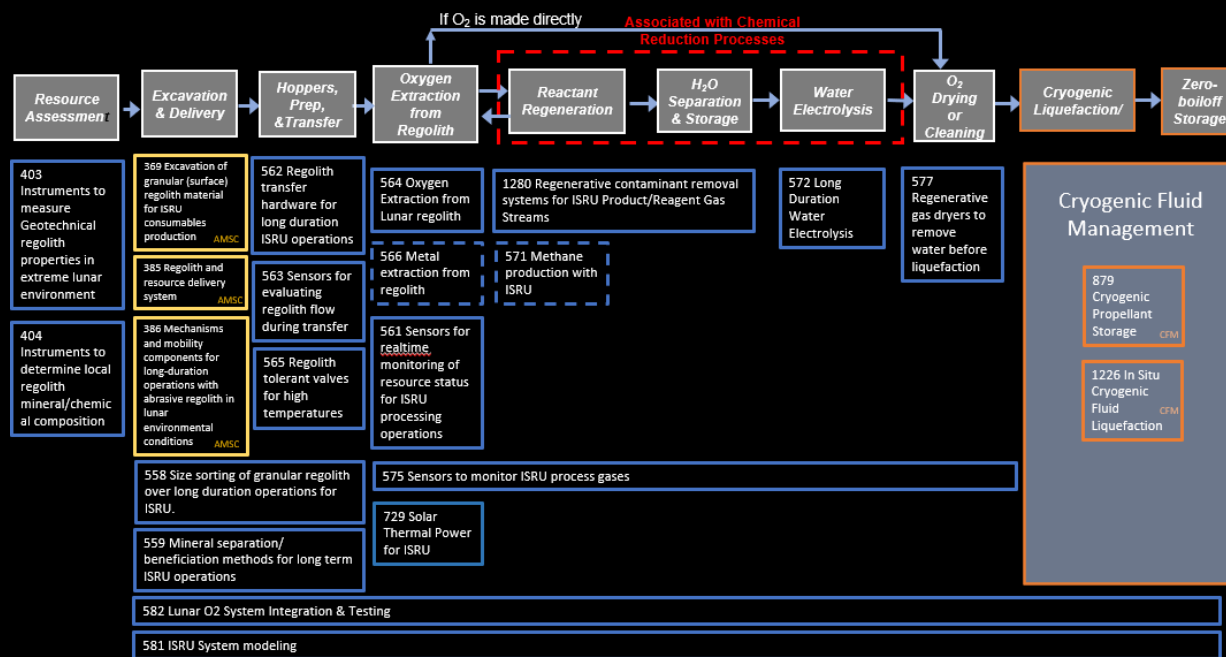
Full-scale implementation & Commercial Operations

LI-7 ^L	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.
OP-11 ^{LM}	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
TH-3 ^L	Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence ; conducting scientific and industrial utilization as well as Mars analog activities.

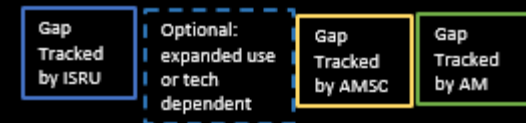
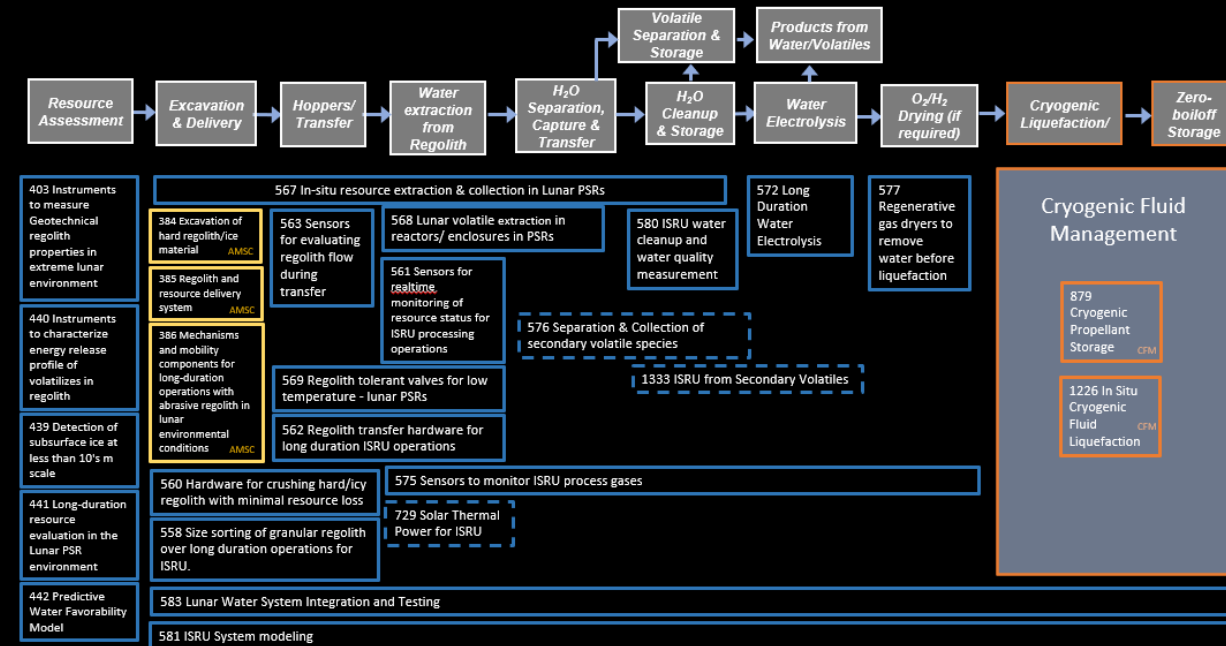
- Dual Path that includes both Water Mining and Oxygen/Metal from Regolith
 - Regolith Processing and O₂/Metal Path supports Surface Construction activities and demonstrations as well
- Ground development of multiple critical technologies in both pathways underway to maximize success and industry involvement
- Resource assessment missions to obtain critical data on mineral and water/volatile resources have started
 - Significant uncertainty if existing missions are sufficient to define resources for design and site selection

ISRU Gaps

Oxygen Extraction from Regolith



Polar Water/Ice Mining

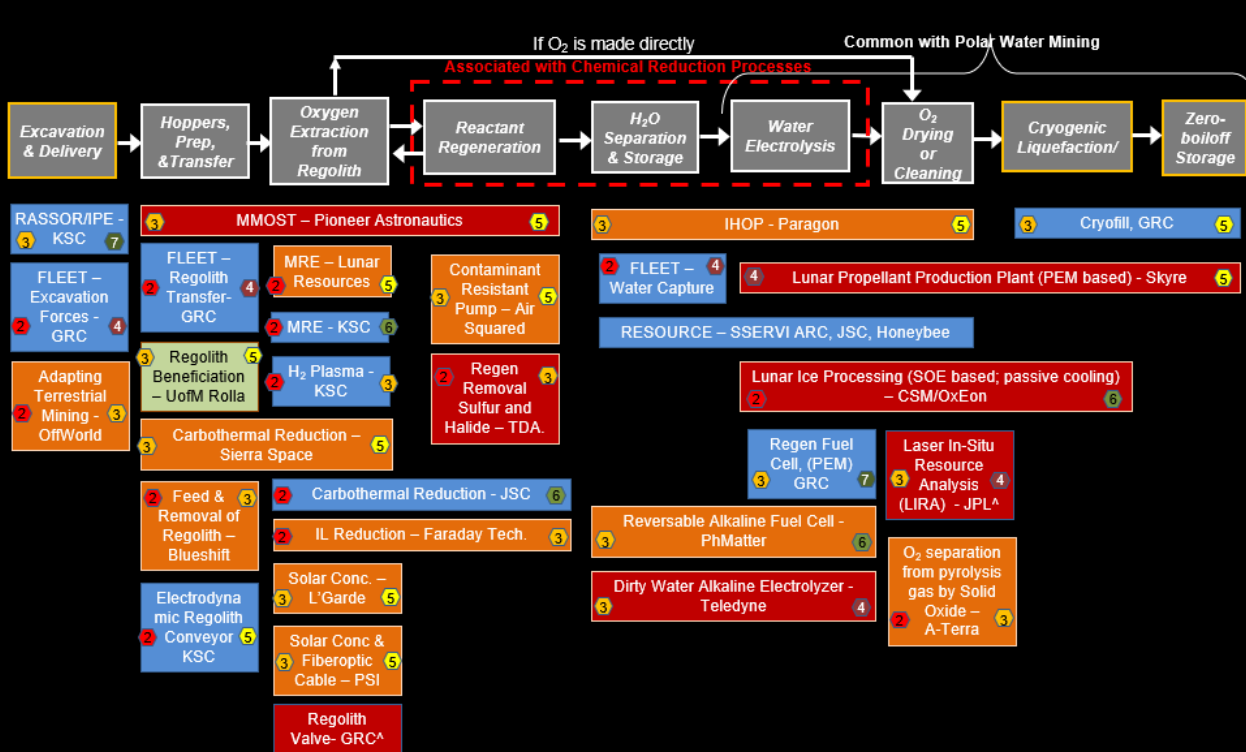


- Gaps were written in three major areas of ISRU:
 - 1) Destination Reconnaissance & Resource Assessment
 - 2) Resource Acquisition, Isolation, & Preparation
 - 3) Resource Processing (sub-divided further)
 - Mission Consumables (Oxygen, Water, Fuels)
 - Feedstocks for Construction and Manufacturing
- Gaps were mapped to six major ISRU 'Systems'
 - Only 2 shown

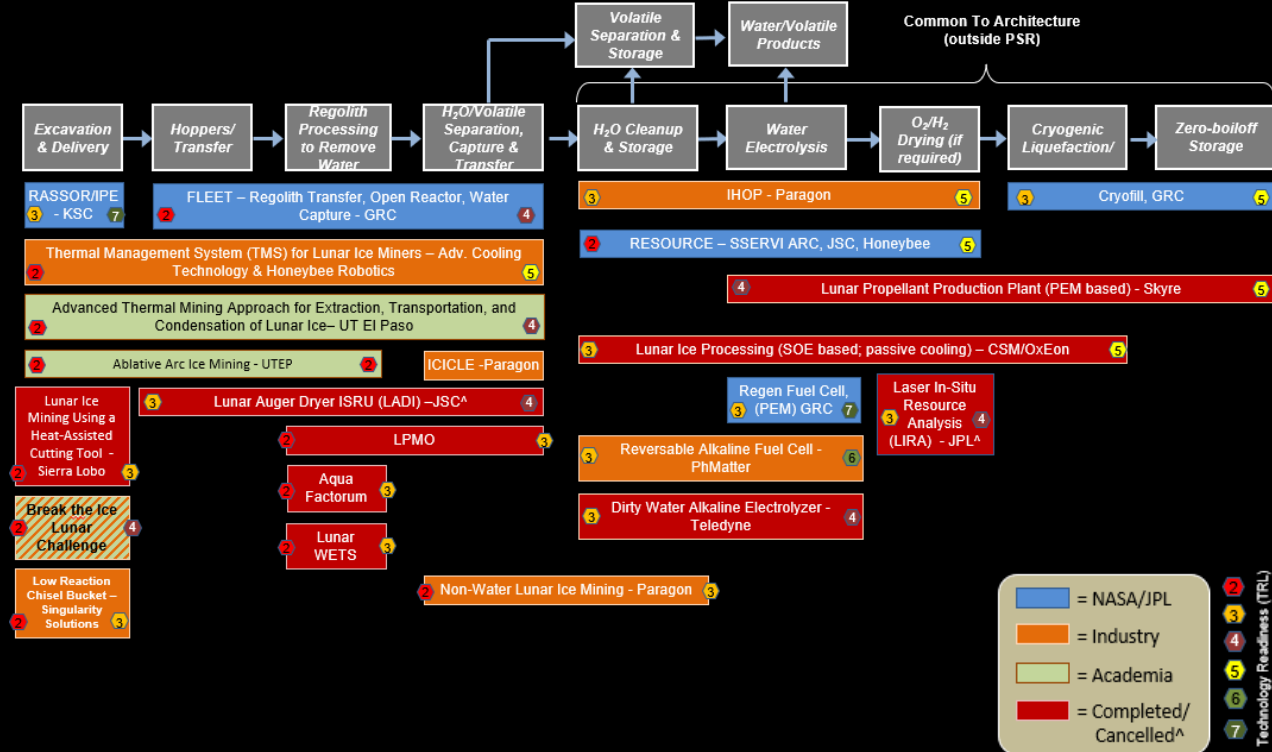
- Gaps were coordinated with other disciplines involved in ISRU end-to-end systems (ex. Excavation, CFM)
- Gaps were coordinated with other disciplines needed to enable ISRU operations beyond those listed in the charts (ex. Power)

NASA / Industry Expertise & On-going Work – By ISRU Focus

Oxygen Extraction from Regolith



Polar Water/Ice Mining



- The bulk of ISRU research and technology development is performed by Industry and academia
- Polar water mining technology work has been either cancelled, low TRL, or completed (under-performed)
- No end-to-end Lunar or Mars ISRU system integration and testing currently funded at this time

Location to Reduce/Eliminate ISRU Challenges/Risks



- Most challenges and risks to ISRU development and incorporation can be eliminated through design and testing under Earth analog or environmental chamber testing at the component, subsystem, and system level
 - **Adequate simulants are critical for valid Earth based testing**
- Critical challenges/risks associated with fully understanding the extraterrestrial resource (form, concentrations, contaminants, etc.) and ISRU system operation under actual environmental conditions for extended periods of time can only be performed on the extraterrestrial surface
- Product quality based on actual in situ resource used should be validated at the destination
- ISRU precursors/demonstrations are extremely beneficial for validation of Earth-based testing and analysis

ISRU Challenges			Earth	Orbital	Surface
Resources	R1	What resources exist at the site that can be used?	S	S	P
	R2	What are the uncertainties associated with these resources?	S	S	P
	R3	How to address planetary protection requirements?	P		V
Technical	T1	Is it technically feasible to collect, extract, & process resources?	P		V
	T2	How to achieve high reliability/minimal maintenance?	P		V
Operational	O1	How to operate in extreme environments?	S/V	P _{NEA}	P
	O2	How to operate in low/micro gravity?	S	P _{NEA}	P
	O3	How to achieve long duration, autonomous operation?	P		V
	O4	How to survive and operation after long duration dormancy	P		V
	O5	How to operate responsibly w/ minimum impact to science/env.	P		V
Integration	I1	How other systems designed to incorporate ISRU products?	P		V
	I2	How to optimize at the architectural level with ISRU?	P		V
	I3	How to manage the interfaces/interactions with other systems?	P		V
	I4	How to deliver in the correct sequence and timely manner?	S		P
	I5	How to grow a commercial ecosystem of supply-demand?	S		V/P

Needs to be performed in lunar environment with actual lunar regolith

Needs significant integrated system testing under analog and lunar environment simulation capabilities

'Responsible Mining' is now becoming very important

P = Primary Location, S = Support Location, V = Validation

ISRU Envisioned Future Priorities - **Next Step Priorities**



- **Initiate solicitations with Industry to progress ISRU technologies to Demonstration & Pilot-scale flights**
 - Pursue oxygen and metal extraction demonstrations; delay water mining demonstration until better knowledge is obtained
 - Provide feedstock technologies and capabilities to support construction demonstrations
 - Identify and pursue new options/approaches for utilizing significant mission mass/frequency capabilities with HLS providers
- **Initiate Internal and Industry-led System-level integration of ISRU and infrastructure capabilities for Pilot/Full-Scale**
 - Expand ISRU system engineering, modeling, integration, and testing to enable technology and system selections
 - Begin combining power, excavation, ISRU, storage & transfer, comm/nav, autonomy/avionics, maintenance/crew.
- **Expand Development of Metal/Aluminum Extraction & other Feedstock for Manufacturing & Construction**
 - Continue and expand work on combined oxygen and metal extraction technologies;
 - Initiate work focused on metal extraction and processes leading to more pure/refined metals
 - Consider longer-term interests in mare regolith minerals and resources: Ilmenite, Pyroclastic glasses, KREEP, Solar wind implanted volatiles
 - Continue and expand construction feedstock/commodity development with in-space manufacturing and construction
 - Evaluate synthetic biology technologies for bio-mining, bio-plastic, and some commodity feedstocks
- **Initiate Mars ISRU Technology and System Risk Reduction Development and Testing for M2M Objective MI-4**
 - Perform system Integration of existing/near-existing Mars human mission scale hardware and perform testing to reduce the risk for architecture insertion
 - Coordinate evaluation of Mars resources and mission insertion with SMD and ESDMD/SOMD
- **Advance Lunar Polar Water/Volatile Prospecting/Mapping and Technology Development**
 - Coordinate Polar Resource Assessment and Mapping (M2M AS-3) with SMD, ESDMD/SOMD, and industry for mining site selection
 - Continue evaluating/developing water mining technologies in parallel with polar resource assessment
- **Initiate Closer-Ties and Coordination with Life Support Systems**
 - Develop needs/objectives, and perform technology assessment/development for nutrients/food/agriculture feedstocks for sustained presence
 - Work with life support on oxygen and water cleanup technologies and requirements
 - Work with life support on conversion of wastes into usable products; eliminate trash dumping



Thank You. Questions?

New ISRU Envisioned Future Priorities at:
<https://techport.nasa.gov/framework>